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A Multidimensional Ecosystem for the 3D Printing Industry and its Potential Effects

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Abstract:3D printing is an additive manufacturing technique which has unique features to transform a digital design file into a physical product, and is changing the world profoundly. The paper aims to explore the essence of a multi-dimensional ecosystem by examining how 3D printing skills are reshaping the world from the perspectives of technology-oriented innovation and social innovation. This paper will introduce the essence of additive manufacturing, not only from the view of technology revolution, but also relating to the social innovation framework. As well as the business model, other elements such as legal systems and social thought and consciousness are discussed.The paper identifies and analyses thevisible process of operation in 3D printing.The paper proposes a new framework after focusing on the investigation of sub-level dimensions, such as, Productivity, Biological Adjustment and Science Cognisance. The paper includes discussion of the relationship between technology innovation and social innovation based on the 3D technology development. Current and proposed future applications are considered, including medical and fashion.

Keywords:*3D printing, AM, multidimensional ecosystem, innovation.*

Introduction

It is a reality today that we can download product data from a website, perhaps re-programme to personalise it to our own preference and taste, and have that information sent to a machine through which the product can be fabricated. This way of operation can build, very rapidly, a physical objectthrough the emerging technology called additive manufacturing (AM), or 3D printing. Human society is being affected by the transformation from subtractive manufacturing to additive manufacturing (Marcel, Ronen& Arne, 2016). With AM, such as 3D printing, data can be taken from an object, such as a ring, which would be a geometric representation of that product in 3D, and convey that data to a machine. This machine builds up the product layer by layer. This is opposed to the traditional method to produce a product by subtractive manufacturing, which removes material from a basic shape, so creating waste. 3D printing, an additive manufacturing process, builds by adding, so reducing waste.

Cost savings play a key role in the industrial society, and each manufacturer is eager to reduce the leftover material from the process of subtractive manufacturing. With AM, during the 3D printing manufacturing process, the material is sprayed by a jet controlled by the embedded computer program to minimise waste. The advantages of AM have generated considerable interest from the industrial and technological fields, and it could profoundly change the world and our lives.

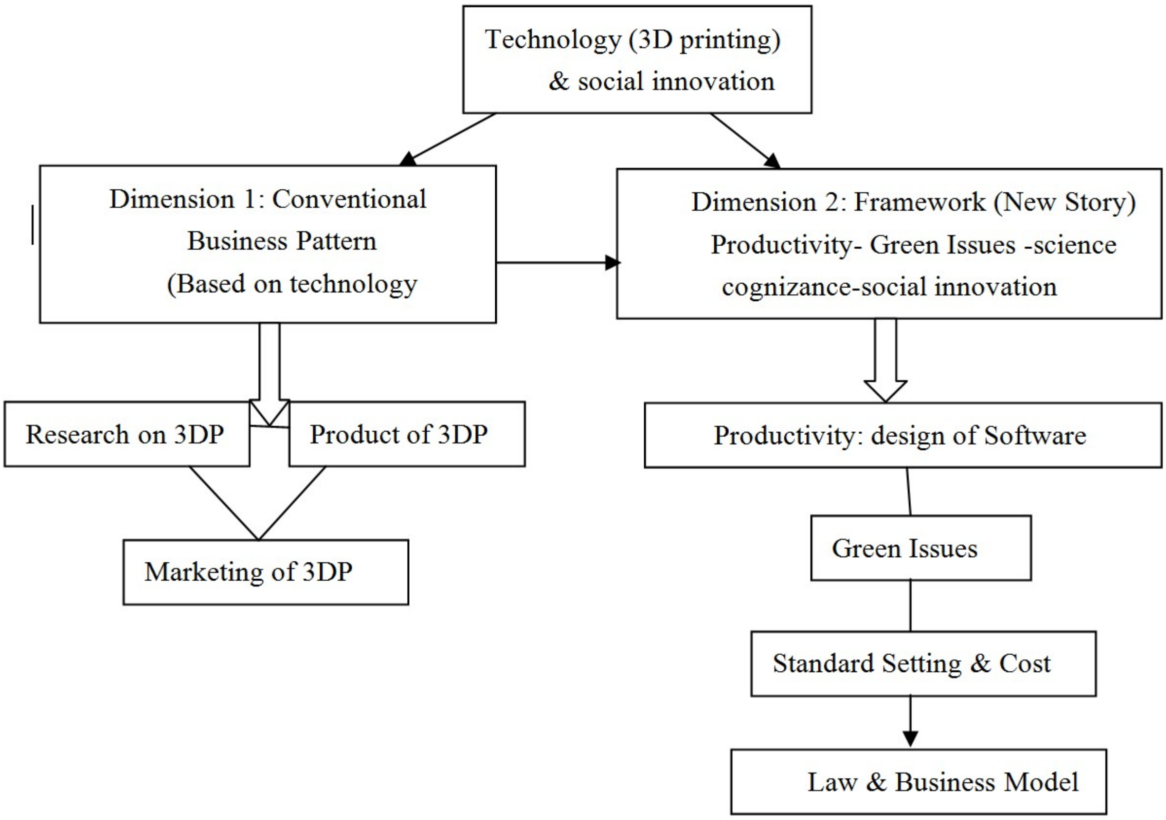
Literature Review

Some research on 3D printing concentrates on the business models, which is almost in the field of social science. Marcel, Ronen & Arne, (2016) state that a consumer goods manufacturer can organise the operations of a more open business model when moving from a manufacturer-centric to consumer-centric value logic. The analysis of the business model components has become a trend of research. Cabirio, Paola & Marco, (2014) emphasisedthat the use of new 3D printing technology in design enterprises should be coupled with proper business model components.3D printing combines industrial manufacturing with the structure of marketing. Jan, Leyland & Pierre, (2015) stated that most manufacturing processes have been "subtractive" in that material is removed (e.g. scraped, dissolved, turned, machined) from a substance in order to produce the desired product. 3D printing turns traditional manufacturing on its head in that it uses an "additive" process. The absence of afeasible and practical business model will be a real barrier for the development of 3D printing. Thierry &Ludmila (2016) discussed the pitfall situation caused by the lack of an effective business model, and they thought 3D printing technologies have the potential to change the way a business models innovation, by enabling adaptive business models and by bringing the "rapid prototyping" paradigm to business model innovation itself.Cost control, value capturing and social cognisance, like law and ethics, have been focused issues in the research. For instance, Christian, Robin & Frank (2015) identified that AM enables the production of complex and integrated functional designs in a one-step process, and the adoption of AM allows a firm to increase profits by capturing consumer surplus when flexibly producing customised products. Legal issues, especially intellectual property rights, mainly occupied the dominant research fields in law (Ben, 2014). Davis (2012) stated that the DIY (do-it-yourself) community, which uses self-designed software programmes, will be at risk of infringing patent law and copyright law. Gerald (2015) argued that the current arms control and transfer policies are not adequate to cover 3D-printed guns, which proves that there is still a "grey area" for 3D printing from the perspective of law and ethics. The social framework still needs to be refreshed or innovatedin order to meet the various requirements from different directions. Thierry, Ludmila& John (2015) initially proposed the new emerging technology provide a "presumption" framework and a typology of co-creation activities.

Methodology

This paper adopts a comparative methodology based on the social and business ecosystem theory. AM, combined with the features and characteristics of IT, shows a total difference from the conventional business pattern. The data-driven technology already imposes great influence on the development of society and on technology itself. This comparative approach displays several dimensions and categories such as with the manufacturer-centric structure and customer-centric structure, production en masse and small scale production, the ownership and lease of means of production, and the difference of standard-settings. The comparison led to a reconstruction of the current business model, legal system, even the social framework and the way of observing the world when the internet is involved (as shown in Figure 1). This comparison is further discussed in the sections on the Multiple Dimensions of 3D Printing and on the Ecosystem of 3D Printing.

Figure 1: Reconstructed Business Model



The multidimensional reconstruction of additive manufacturing, together with the use of the Internet, revises the conventional circulation by the traditional business pattern, and proposes the potential framework which could happen in the future.

3D printing: from Technology-changing to Society-changing

The advance of technology leads the way to the future and success, although technology often struggles to meet the rapidly growing requirements. Currently, technology has been embedded into the entire industry, from the industrial design to the physical production. Both the capital investors and engineers try to make the effort to create a win-win business pattern for benefit sharing. Nevertheless, the social framework brought about with this technology-oriented change needs also to change, resulting in innovation.

The Conventional Business Pattern

Before the Industrial revolutions, businesses were small, and most of their trade was local, based on a farming society. Trade over long distances were restricted mainly to luxury goods. Business patterns were simple.The customer was often in direct contact with the producers.

With the coming of the next age, the industrial society led to central manufacturing, with global distribution. It had seemed that this business pattern would continue forever. New technology was invented in the laboratory, so technical transformation in the factory improved mass production without personalisation. The products from this process of industrialisation appeared in the market with a value label and were evaluated by price. This formed the chain of "research-product-market" which is typically labelled as prosperous industrialisation; whereby the circulation of these elements profoundly affected the contemporary industrial society. However, the emerging additive manufacturing, 3D printing, totally merge the producer and consumer into one entity rather than splitting them which often happens in the conventional business pattern.

A New Story

Today a customer could sit at home, making an order online so acquiring the commodity the customer wanted. The internet now plays an important role in the human society. A manufacturing business could now advertise its services online, making effective use of social media. After receiving an order from a customer, the business could customise the design and e-mails it to a 3D printing service close to the home of the customer. This would mean that the transfer of products between continents would be greatly reduced.

This approach is very different from the current model of design-manufacture-market, where the customer would have little contact with the designer or manufacturer. The current personalisation of goods is normally restricted to choices from a limited menu of options.This current approach typically involves the transport of goods over long distances.

Compared with the current manufacturing and marketing, additive manufacturing is based on technology innovation, bringing about unpredictable social innovation. The technology of 3D printing is still in the introduction stage of its life cycle. During the incubation period of AM, the technology has to face various challenges and barriers. In the previous technical revolutions, these requirements and barriers were overcome by the efforts of technicians and inventors. AM initially appeared about thirty years ago, but the investors and the general public have only recently become aware of the development of AM. It is the wide use of the internet that enabled the close interaction between new emerging technology and business model for sale, marketing and communication. 3D printing is characterised as a revolutionary and practical technology which has attracts the interest of many market leaders and its market potential looks promising so that the international organisations areintensifying their R&D. The media often uses phrases such as “this technology has a bright future, not least in rapid prototyping, but also in the manufacture of many kinds of plastic and metal objects, in medicine, in the arts, and in outer space”. This is based on technology-orientation, rather than social-orientation. As social science has lagged behind on the possible effects of 3D printing, there is a need for detailed and systematic research on the business model, green issues, energy saving,with AM, as with the growth of additive manufacturing, various social problems will follow. As the times of “Industry 4.0” are approaching, IT (Information Technology) could have a profound impact on the ways in which human beings produce goods. The gap between manufacturers and consumers will be eliminated, and many social issues will be changed.

The Multiple Dimensions of 3D Printing

In the following, the multidimensional contents will be discussed, regarding the essence of AM, 3D printing in the current situation, and in the future.

The Technical Dimension: Visible or Invisible Process of Operation

The new 3D printing technology typically reads CAD data which is product design data created on professional product design programs. It could be a professional product designer, oran architect who creates a product in 3D. Data collected will be sent to a machine through which data would be sliced into two-dimensional representations of parts of that product. That data, causes the machine to deposit material, layer by layer, starting at the base of product, fusing the new layer of materials to the previous layer in an additive process. These layers vary from a few millimetres in thickness, to less than four micronsfor a microstructure

The material that is deposited either starts as a liquid form or a material powder form. The bonding process can happen by melting then depositing or depositing then melting. Ina number of hours, we can build a complicated physical product, ready to take out of the machine and use. The products range from shoes, jewellery made out of stainless steel, phone covers made of plastic, all the way through to spinal implants, created out of medical-grade titanium, and engine parts.

With the application of 3D printing skills, structurescan be created that are more intricate than any other manufacturing technology can achieve, or that are impossible to build in any other way. The 3D technology skills can be applied successfully to produce moving components, hinges, parts within parts. In some cases, manual labourcan be abolished in the manufacturing process. Architects could build a house using AM, for example the architectural firm, Shiro, whichbuilt a house by depositing artificial sandstone, layer upon layer.

The Social Innovation Dimension: the change of framework

The social framework is changed bythe advancement of technology. The invention of ironware totally changed the agricultural society, and the invention of the steam engine led Britain to the first Industrial Revolution. The invention of electricity and computers also led to major changes in society. The means of production had changed, and division of labour had become more specialised. 3D printing could lead to major changes in society. Although it is difficult to make a serious prediction, the current industrial processescould be, at least in part, overturned by 3D printing.

Productivity: Design of Software

Many scientists involved in AM research are exploring how to enlarge the market of 3D printing, as the needs of customised products have become the consumption trend with internet marketing. Compared with the standardisation in the conventional pattern, customisation represents the trend catering for the target consumer group.

Biological Adjustment: Green Issues

AM, rather than the subtractive manufacturing, produces only the products without the waste. The transportation and manufacturing carbon footprint of many products, using AM, could be reduced as DIY designs, rather than products, are transported around the world.

Technical Cognition: Standard Setting & Cost Control

Technical Cognition refers to the growing understanding which vastly depends on the development of technology and the application by the operator.

National standards and industry standards exist in the conventional industrial society, though these need to be altered for 3D printing. Compared to the standard of the past which tended to lag behind the current state of technology, the standard setting of the future will need to be constantly flexible and diversified because of the human factor. It will soon prove that there are two levels of standard setting in 3D industry system which is divided to fixed and flexible, usually referred to as traditional standard and standard by DIY customisation.

In addition, the cost control in 3D printing could be much easier than in the conventional industrial manufacturing.

Social Cognition: Law & Business Model

Social cognition refers to the superstructure such as law and business model which are based on technical cognition, productivity and biological adjustment. AM has the potential to be as disruptive as the personal computer and the internet. The digitisation of physical artefacts allows for global sharing and distribution of designed solutions, leading to problems of patents and copyright.

The Ecosystem of 3D Printing

Human Ecology and Ecosystem

3D printing is designed to serve the users and customers. This echoes the core and ultimate aims of society. Amos H. Hawley (1950) proposed that the environment, population, and the ecosystem tend to move toward equilibrium. In his theory, Human Ecology, Hawley wrote that humans will modify their behaviour patterns to fit with changes in their biophysical environment. Through this adaption human groups can either evolve or expand into complex societies. For systemic change to occur, such as expansion of a population, disequilibrium is required along with multiple challenges to the environment.

This environment of 3D printing involving design of software, green issues, standards setting, cost control, legal system and business models, profoundly change our way to adapt to the contemporary society. The multidimensional system is gradually evolving into a social organism with manifold contradictions. These conflicts are the essential elements integrating in the process of crashing and collision, which could include conflicts between additive production and subtractive production, production en masse and small scale production, ownership of means of production and lending, technical innovation and social innovation. After reorganising and reconstructing the framework, human ecology merges with the human environment, which embeds and alters in the development of 3D printing, and it finally forms an ecosystem.

Checks and Balances

The ecosystems of planet Earth are coupled to human environments. Ecosystems regulate the global geophysical cycles of energy, climate, soil nutrients, and water that in turn support and grow natural capital. Ultimately, every manufactured product in human environments comes from natural systems.

The environment of 3D printing nourishes the growth of new technology, and the practice of additive manufacturing in turn develops the social framework. Even though the conflicts mentioned above will interact with each other to be real barriers or restraints for 3D printing, the system of checks and balances like the leverage eventually narrows all the gaps and differences. However, what we should do is not to wait for the changes, but only try to change and compromise all the essential elements actively by ourselves.

Current and Future Issues

Medical Applications

AM has many uses from education and training, pre-operative planning and for explaining the medical situations to patients. This is in addition to producing prostheses including casts for broken limbs, such as by "Evil Designs" using AM to produce light weight polymer based casts including holes that allow air to circulate around them(Michalski& Ross, 2014).The skeleton structures could be produced by AM for children, which would stretch with their growth and be absorbed into the body within a few years so reducing the necessity for a further operation to remove the structure.

The current development of additive manufacturing has already started to have an impact in the medical field (Owen, 2012). The production of 3D printed items formed from body scans, has been used to build models to assist the surgeons in planning of complex surgery. This reduces the operation time by as much as 70%, so resulting in better potential survival for the patient, with faster recovery so reducing post operation hospital bed usage, reducing costs both for the operation and the post-operative care. Companies such as Materialise UK(2017), specialise in producing models for this pre-planning using 3D models in addition to making, by 3D printing, replacement parts, such as knee and hip joints. By producing both the replacement joint and the model of the patient’s socket, the fit could be tested in advance, so reducing the number of slightly different shape joints that previously had to be tried in the patient's body in order to find the best fit and those not successful had to be destroyed to avoid infection of another potential recipient of that part.

By using AM, the cost for a procedure could be reduced to one per cent of the previous cost. AM prostheses can be personalised to take account of the weight, activities and preference of the recipient.Problems have been experienced in China when joints had been imported from Western countries which did not account for the difference in body structure between the Chinese and the Westerners (Michalski& Ross, 2014).These AM personalised joints could be of particular benefit to the more rural western parts of China, where there is less local technical and medical expertise, so producing better personalised fits, at reduced cost and reducing also the duration of stay in hospitals from say seventeen to possibly four days as in Western countries (Sheng-Li Huang, Xi-Jing He &Kun-Zheng Wang, 2012).

In addition to the cost of the initial prosthesis, there is the future cost of maintenance, especially for children. It is has been proposed that an AM hand once provided, could be replaced as a child grows, or the prosthesis becomes damaged such as in sports or games, with a replacement AM hand which could be created at a local centre with minor adjustments as the child grows.

This is particularly appropriate for Third World countries especially those in war zones, where local AM hubs could be developed to scan to identify the required shape, without using the slower and potentially painful previous method of using plaster, and then using AM possibly with slightly lower functionality limbs at a cost of under £50 within one week. With the use of professional medical and technical volunteers and of open source software, AM is being developed for third-world and war zone areas to produce personalised limbs, at very low cost, although in some cases with more restrictive functionality, for almost immediate operations, such as are being developed by the Enable Community Foundation - Enabling The Future, (2017). These have been producing prosthetic hands, especially for children, using low cost 3D printers for approximately £40 which can be in any colour to match their skin or possibly as chosen by a child in their favourite colour. Over 500 children worldwide have chosen a futuristic "Cyber Beast" AM produced prosthetic hand rather than the more conventional shape, although their preference might change as they approach maturity.

The opportunities for dentistry, to provide comfortable well-fitting dentures especially for Third World countries, could be provided by using 3D printing technology. The relevant mouth could be scanned at the closest equipped hospital, the scan being sent via the Internet to the remote experts who would design the false teeth, test with a 3D model of the dentures as well as the actual mouth, and when satisfied, send the denture design file to a print centre. This centre could produce, using composite materials, a comfortable, effective and attracted set of personalised false teeth. These could be reconstructed easily if the original dentures were lost or damaged.

The use of 3D printing for personalised hearing aids is currently available. Other opportunities provided by additive manufacturing that exist currently and in the future, for the benefit of patients, especially remotely in underdeveloped countries, are changing health care.

Fashion

The design and production of personalised jewellery already exists using this technique, by designers such as Kimberley Ovitz. Dresses are also being produced by 3D printing such as for weddings in China for Cismo Bride. Use of AM is of particular benefit to small design houses, where they no longer have to source a manufacturer for conventional production, and also commit to minimum quantities. These designers can put their designs to market much faster (Fashionista, 2017). A dress produced, in approximately 120 hours by 3D printing, was shown worldwide in the opening ceremony of the 2016 Paralympic Games, when the dress was worn by Amy Purdy, a double amputee who was a Paralympic gold medallist in addition to being a runner up on the American Stars in Their eyes (Paralympics 2016). She wore this dress to dance a samba with an industrial robot. The designer of the dress, DanitPeleg, was reported as saying that the limitations on design were now only restricted by the imagination of the designers (Paralympics 2016).

Fashion for the Elderly and Disabled

The opportunities to improve the well-being for the elderly and the disabled, by producing attractive, comfortable personalised clothes, are now technically available. This could lead to better mental as well as physical health as it would include Interaction such as social dancing, leading particularly for the disabled to international standard dancing competitions which already exist including international competitions such as for wheel chair users.

By using a full body scan for those able to stand, designed clothes can be adapted to suit the different body shapes, especially as many elderly people gradually change from the upright to a more forward curved position, requiring adjustments such as to the length of jackets and dresses in the front compared with that at the back. Special body scanners are needed for those restricted to wheel chairs, to obtain slightly different measurements in order to produce comfortable, useful and attractive personalised clothes. Local charities could assist with the arrangements for the scanning and also the collection of the 3D printed clothes.

Future Purchasing

In the future, once the body scans have been taken, clothes can be designed or standing designs modified, and possibly shown on a hologram of the customer for their agreement. The personalised 3D printing design could then be sent to a local 3D printing centre for production.

Green Issues

By significantly reducing waste in the manufacturing process, 3D printing also could enhance global "resource productivity" - that is, getting more "product" out of the same quantity of a given resource. This could ease the growing gap between supply and demand for non-renewable resources.

The current concept of organising gifts to be ordered from companies such as Amazon (2017) and dispatched to the recipient, can be further improved to reduce the transport delay, cost and the carbon footprint. Currently goods are often produced centrally and then sent from their own port in containers throughout the world by sea or possibly by air, for example, Foxconn Inc.(2017),the giant manufacturer in China, has its own R&D centre factory with logistics system, container port, and distribution centre. One of many of its factories (located in Shenzhen, Guangdong Province), employs more than 300 thousand workers. The output of this one branch factory is 2400 international containers which will be loaded on board quickly and transported to other countries around the world.

This practice could be modified by the organisation maintaining its centralised head office but generating a series of local 3D printing centres to manufacture the items. The basic materials for 3D printing would still need to be transported in bulk, but would require less space than the finished product especially with the removal of unnecessary packaging hence reducing the cost as well as the carbon footprint. In some cases, with the increase in home 3D printers, the recipient could print their own gift at home.NASA announced in 2014 that they planned to try out the use of a3D printers in the International Space Station so that replacement parts could be produced immediately, rather than the delay and cost for a special space shuttle to deliver a critical part.

By reducing the amount of transport and the extra packaging for transportation, these financial and carbon footprint costs can be reduced. By developing recycling of 3D printed items, the carbon cost would be the power required which could, in many Third World countries, be provided by solar power.

To minimise the increased amount of micro plastic in the oceans, which is now getting into the human food chain, plastic could be recycled into plastics in a suitable form for additive manufacturing. This uses less energy than conventional recycling of plastic.

Employment Changes

The growth of additive manufacturing can cause a change in employment worldwide, just as in the development of supermarkets and of major organisations, such as Amazon, has affected the viability of small local businesses. The development of additive manufacturing could change the concept of a large central manufacturing plant with worldwide distribution by sea or air of their products, then further local distributions. The new structure might be a centralised design location, then very small localised AM plants. This would be a change in skills requirements with an increase of local based technical experts to assist in the printing with others for final finishing and local distribution or collection. There would be a need for the localised scanning centres, whether for required replacement parts or to record human shapes, to be passed either to the design centre then onto a localised printing centres, or possibly with in-house AM facilities. The scanning centres would need employees with possibly both technical and soft skills to assist and advise the clients. These local centres could also handle payment issues. This in turn could affect the transport system and the location of homes.

Barriers

Currently the cost of both the scanners and additive manufacturing equipment, together with the time and ability to print larger items, needs to be improved. The ability to handle composite materials, both in printing and recycling, needs further development.

These new skills needed for the future needs to be included in school and college courses, whether technical, design or an understanding of the opportunities of additive manufacturing.

Conclusion

Throughout the paper relevant to the emerging additive manufacturing, 3D printing is reshaping the world. There is a need for detailed and systematic research on the business model, legal issues, green issues, including energy saving. Other research is needed to identify which social groups will be early adopters, as customers or entrepreneurs, also which types of manufactured goods are best suited for this approach. Possible problems, such as the replacement of broken or worn parts, and the recycling of mixed material products, need to be investigated.

The development of 3D printing technology and its application into different fields are actually challenging many so called mature and solid social science, legal and marketing concepts. What surprises and fascinates organisations, the general public and students is the power of 3D printing. Its existence has begun to motivate researchers, academics and even students to scrutinise the validity and reliability of many marketing concepts and framework.

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